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THE ALPINE FLORA OF THE WHITE MOUNTAINS, CALIFORNIA

PHILIP W. RUNDEL
Department of Ecology and Evolutionary Biology and
Center for Embedded Networked Sensing, University of California, Los Angeles, CA 90095
rundel@biology.ucla.edu

ARTHUR C. GIBSON AND M. RASOUL SHARIFI
Department of Ecology and Evolutionary Biology,
University of California, Los Angeles, CA 90095

ABSTRACT

The alpine zone of the White Mountains of California, defined as non-forested areas above 3500 m, includes 163 native species of vascular plants in an area of 106 km^2. No invasive species have become well established. Nearly two-thirds of the native species occur in just seven families, led by the Asteraceae with 30 species. Six genera have five or more species, led by *Carex* with 14 species. Life forms of the flora are heavily dominated by broad-leaved herbaceous perennials (53%), followed in importance by graminoid perennials (22%) and mats and cushions (11%). Woody shrubs, chamaephytes (low subshrubs), and annuals are relatively few in number, and those species present are generally more characteristic of lower elevation communities. Fellfields form the characteristic habitat for 41% of the flora, while moist meadows and open slopes habitats characterize 24 and 22% of the flora, respectively. Only 31% of the flora is restricted in the White Mountains to the alpine zone, while nearly a third of the alpine flora has a range extending to lower elevations of the montane or cold desert zones below 2900 m. The alpine flora of the White Mountains shares over 70% of its species with the Sierra Nevada. Only three species are endemic to the alpine zone of the White Mountains: *Draba californica*, *D. monoensis*, and *Potentilla morefieldii*.

Key Words: alpine biogeography, alpine flora, plant life forms, White Mountains.

Generalizations about the patterns of biodiversity and life forms in alpine floras have largely come from research conducted in relatively mesic alpine habitats with summer rainfall regimes, as for example in the Alps of central Europe and the Rocky Mountains of the western United States (see reviews by Tranquillini 1979; Chapin and Körner 1995; Körner 1999; Bowman and Seastedt 2001). Unlike the majority of alpine regions in the Northern Hemisphere that share elements of a circumboreal arctic-alpine flora, the high mountain ranges in California have developed a unique alpine flora under the influence of mediterranean-climate conditions with relatively dry summers added to other alpine environmental stresses. Although broad ecological studies have been carried out in the alpine elevations of the Sierra Nevada and White Mountains of California (Chabot and Billings 1972; Major and Taylor 1977; Morefield 1992), there is still a relatively poor knowledge of patterns of floristic diversity and life form distribution of the alpine flora for these ranges.

The White Mountains of California and adjacent Nevada (Fig. 1) present a particularly interesting area for study. This mountain range is positioned at the interface between two major geomorphic provinces, the Sierra-Cascade Province and the arid Basin and Range Province, yet is isolated from direct contact with high elevations of either sets of ranges. Moreover, warmer and more xeric climatic conditions during the Altithermal period of the early Holocene allowed an upward movement of subalpine conifers, restricting the area available for growth of alpine communities (Jennings and Elliot-Fisk 1991, 1993). Thus, the White Mountains present an example where both climate history and geographic isolation have played significant roles in the evolution of the alpine flora.

Lying in the rain shadow of the Sierra Nevada, the White Mountains receive only about one-third of the precipitation reaching similar elevations on the west slope of the Sierra Nevada. These arid conditions, combined with the extremes of low temperature, wind, low atmospheric pressure and high ultraviolet radiation load that characterize most temperate alpine conditions, produce unusually severe conditions of environmental stress for plant growth. Adding to the habitat conditions of the range are high levels of both topographic diversity and geologic complexity, with the latter including granites, dolomites, shales, limestones, and metavolcanics (Nelson et al. 1991; Ernst et al. 2003) that have strong influences on florisitic composition (Lloyd and Mitchell 1973; Marchand 1973; Rundel et al. 2005).

The White Mountains extend approximately 60 km from their northern end in Nevada across into California and Westgard Pass in the

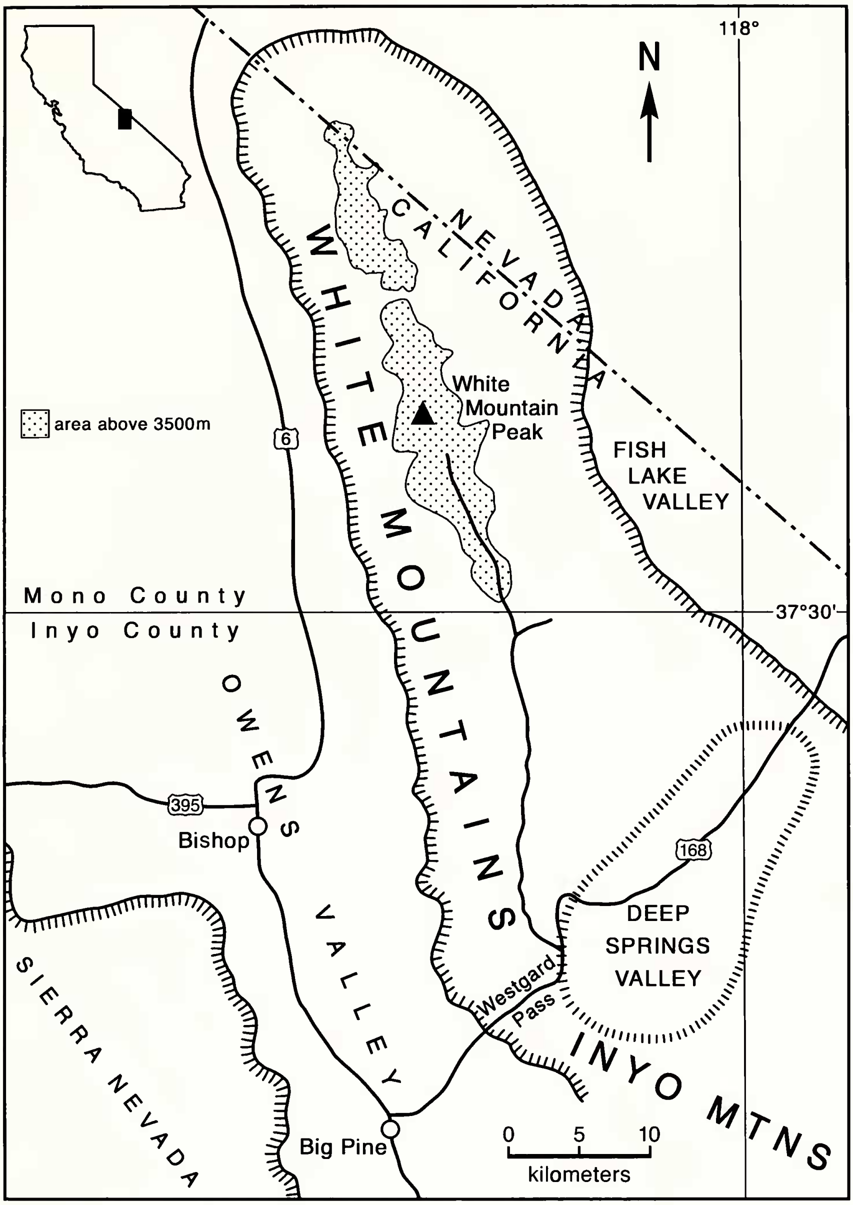

FIG. 1. Regional view of the White Mountains of eastern California and adjacent Nevada. The stippled area is that portion of the range above 3500 m elev.

south, or three times this length if the contiguous Inyo Range south of this pass is added (Fig. 1). The range is very narrow, however, with a width averaging only 20–25 km. As a result, the range rises sharply from elevations of 1250 m in the Owens Valley to a high point of 4343 m at White Mountain Peak over a lateral distance of less than 10 km. This peak is tied with Mount Shasta as the third highest summit in California.

There has been a long history of floristic and ecological studies in high elevations of the White Mountains where alpine habitats are present. The floristic diversity and relationships of the full flora of the White Mountains has been described in considerable detail (Lloyd and Mitchell 1973; Morefield et al. 1988; Morefield 1992). Although there have been ecological studies of plant-soil relationships in the alpine regions of the range (Mooney et al. 1962; Mitchell et al. 1966; Marchand 1973; Ernst et al. 2003), no floristic research has focused on the alpine region above 3500 m or analyzed its characteristics specifically. In this paper we present a broad overview of the alpine flora of the White Mountains by providing a detailed analysis of the floristic richness, ecological diversity, and biogeographic relationships of the alpine flora present within this zone.

Materials and Methods

Floristic Richness and Life Forms

The alpine flora of the White Mountains in this study was considered to include all species with a known occurrence above 3500 m, an elevation limit roughly corresponding to upper treeline, although *Pinus longaeva* reaches elevations of up to about 3700 m in scattered locations. While there are certainly alpine-like communities and species assemblages below this elevational limit, an occurrence above the upper limit for growth of *P. longaeva* and *P. flexilis* indicates a definitive alpine habitat. Our listing of the alpine species to be considered was based on a careful examination of published material (Lloyd and Mitchell 1973; Morefield et al. 1988; Morefield 1992; Hickman 1993), herbarium records (Cal Flora, White Mountain Research Station), and our own field observations carried out on numerous visits each summer from 1999–2006 . Scientific names used here follow those of Hickman (1993), with the exception of *Poa pattersonii* which has been divided into *Poa abbreviata* subsp. *pattersonii* and subsp. *marshii* (Soreng 1991).

Adapting the broad classification scheme set out by Morefield (1988, 1992) for the entire flora of the White Mountains, we developed a system to categorize the alpine species by life form, ecological habitat, elevational zone, and biogeographic distribution. Each alpine species was placed into one of six life forms in a modified Raunkiaer (1934) classification: phanerophytes (shrubs reaching 50 cm or more in height), chamaephytes (subshrubs lower in stature), mat or cushion plants (<10 cm in height and prostrate in growth, perennial graminoids (i.e., Poaceae, Cyperaceae, and Juncaceae), broad-leaved herbaceous perennials (tussocks, rosette perennials, biennials, and geophytes), and annuals (therophytes). With very few exceptions, plant species in the alpine zone have very narrow leaves or leaflets with blades <10 mm wide, and would be classified as leptophylls with leaf surface areas <25 mm^2 (Raunkiaer 1934).

Designations of ecological habitats were adapted from characterizations of Morefield (1988, 1992) and our experience to provide seven categories. Along a rough gradient of mesic to xeric these ecological habitats are aquatic sites, wet sites (areas with saturated soils and riparian habitats), moist sites (e.g., wet meadows and areas with snow melt accumulation), fellfields with seasonal moisture availability, talus slopes, open slopes, and dry rocky slopes. Where a species occurred broadly across more than one of these habitat categories, it was placed in what we considered its most typical habitat.

The classification of species by characteristic elevational zone was designed to separate obligate alpine species from those extending above 3500 m but also occurring at lower elevations. These five categories listed as the elevational belts of lowest occurrence in the White Mountains are cold desert (1220–1980 m), montane (1980–2900 m), subalpine (2900–3500 m), alpine (3500–4000 m), and high alpine elevations (4000–4332 m). The montane zone roughly corresponds to the pinyon-juniper zone and the subalpine belt to the upper pine zone of vegetation.

The biogeographic range of each alpine species was classified into one of five categories. These were: widespread species present in many habitats or regions throughout the world or across North America, cordilleran species widespread in mountain regions of the western United States, Sierra/Cascade species, intermountain species widespread across the Great Basin, and species endemic to the White Mountains.

Climate Regimes

Climatic data to characterize the alpine environment of the White Mountains was taken from long-term records collected at the Barcroft Station at 3801 m elev. (37°35′N lat., 18°15′W long.) for the period 1953–1973 (Pace et al. 1974; Powell and Klieforth 1991). The mean monthly maximum temperatures at Barcroft vary from a high of 11.9°C in July to a low of −5.3°C in February (Fig. 2). Record maximum temperatures of 22°C have been reached in July and August. Mean monthly maximum temperatures remain below freezing for six months of the year, from November through April. Mean minimum temperatures range from a high of 2.4°C in July to a low of −14.0°C in March. Mean minimum temperatures drop below freezing for every month of the year except July and August.

Mean annual precipitation at Barcroft Station is 478 mm (Fig. 2). There are elements of a mediterranean-type pattern of winter precipitation but with a strong influence of summer convective storms from the east that bring scattered precipitation events throughout the growing season. Mean monthly precipitation ranges from a high of 56 mm in December to a low of 18 mm in September, but year-to-year variation is high. The extremes in annual precipitation over the record period have ranged from 242 to 852 mm. With the exception of the summer months of July through September, all of this precipitation falls as snow.

Results

Native Flora

Defining the alpine zone as non-forested areas occurring at or above 3500 m, the alpine flora of

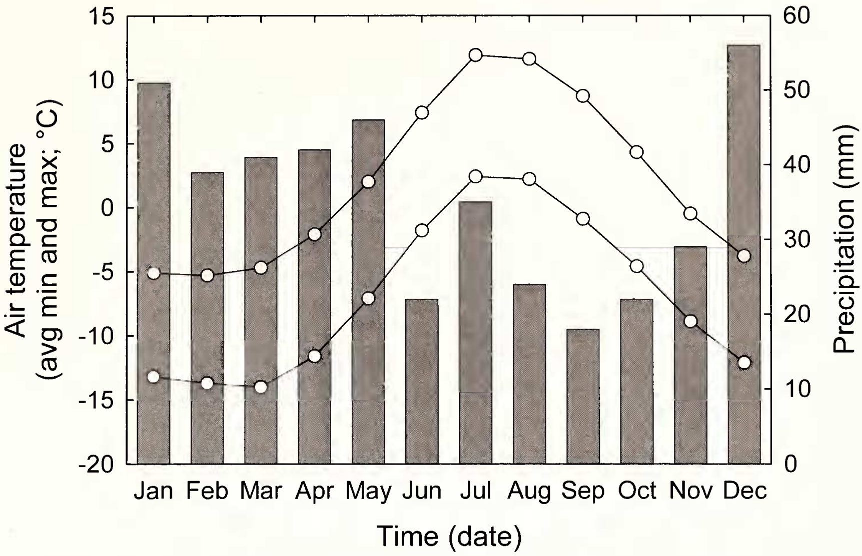

FIG. 2. Mean monthly climatic conditions at the Barcroft Station at 3801 m in the White Mountains, 1953–1973. Data from Pace et al. (1974).

the White Mountains includes 163 native species occurring in an area of 106 km². Rather than representing the proportional family relationships of the California flora overall, the alpine flora has just seven families that account for nearly two-thirds of its total species. Leading this group is the Asteraceae with 30 species, followed in order by the Brassicaceae (18 species), Poaceae (17 species), Cyperaceae (15 species), Rosaceae (9 species), Caryophyllaceae (9 species), and Polygonaceae (7 species). Genera with large numbers of alpine species in this flora include *Carex* (Cyperaceae, 14 species), *Arabis* (Brassicaceae, 7 species), *Draba* (Brassicaceae, 7 species), *Poa* (Poaceae, 6 species), *Potentilla* (Rosaceae, 5 species), and *Eriogonum* (Polygonaceae, 5 species). Several species just miss our lower elevational limit of 3500 m, and thus are not included in our figures here, although they occur in alpine fellfield and open slope habitats. These include *Antennaria dimorpha* (Asteraceae), *Tonestus peirsonii* (Asteraceae), and *Eriogonum umbellatum* var. *covillei* (Polygonaceae).

The life form distribution of the native alpine flora of the White Mountains is strongly dominated by herbaceous perennials, as is typical of temperate alpine habitats elsewhere. Within herbaceous perennials, the assemblage of perennial graminoids (most notably grasses and sedges) form 22% of the total flora, mats and cushions form 11%, and other herbaceous perennials such as broad-leaved tussocks, rosettes, and biennials form 53% (Fig. 3). Combined, herbaceous perennials thus comprise 86% of the flora.

There are 18 native species of mats and cushions, all low in stature and mostly relatively small in size, that make up a heterogeneous group that shares the characteristic of a prostrate growth form with either a central taproot or multiple points of rooting through layering. These form an ecologically significant component of plant cover on fellfield slopes and the margins of drainage swales. A different group of species is present, however, dominates on granitic versus dolomitic substrates. Common mats and cushions on the widespread granitic substrates include *Draba oligosperma* (Brassicaceae), *Trifolium andersonii* var. *beatleyae* (Fabaceae), *Eriogonum ovalifolium* var. *nivale* (Polygonaceae), and *Penstemon heterodoxus* var. *heterodoxus* (Scrophulariaceae). On dolomitic substrates, there is a shift in dominance to species such as *Erigeron pygmaeus* and *Stenotus acaulis* (Asteraceae), *Astragalus kentrophyta* and *Oxytropis parryi* (Fabaceae), *Linum lewisii* (Linaceae), *Eriogonum gracilipes* (Polygonaceae), and *Castilleja nana* (Scrophulariaceae). These dolomite species , however, may occur on other soil parent materials over their ranges.

Shrubs (phanerophytes) and subshrubs (chamaephytes) are few in the alpine flora of the White Mountains. Just three shrub species reaching heights of 50 cm have a range that extends above 3500 m: *Ribes cereum* (Grossulariaceae), *Potentilla fruticosa* (Rosaceae), and *Salix orestera* (Salicaceae). All of these shrub species are more typical of lower elevations. Only *Ribes cereum* is common in the alpine zone, and its distribution is highly correlated with large granite outcrops where thermal and hydrologic characteristics may be significant in providing favorable microsites for this species.

Seven species of low woody subshrubs are present, representing just two families. These are

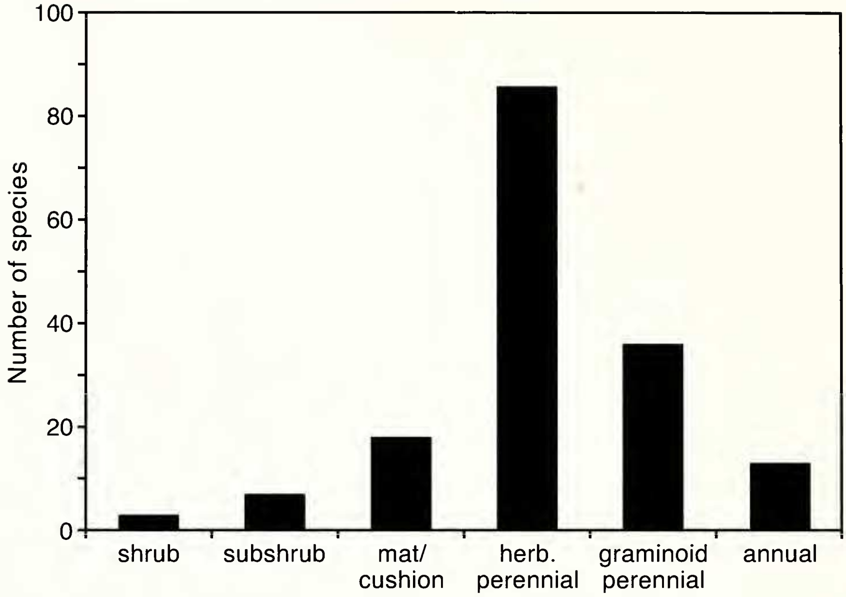

FIG. 3. Life form distribution of the native vascular plant species in the alpine zone above 3500 m in the White Mountains.

Artemisia rothrockii, *Chrysothamnus viscidiflorus* subsp. *viscidiflorus*, *Ericameria discoidea*, and *E. suffruticosa* (Asteraceae), and *Leptodactylon pungens*, *Linanthus nuttallii* subsp. *pubescens*, and *Phlox pulvinata* (Polemoniaceae). These three Polemoniaceae are quite low in stature in their alpine habitats and approach becoming mats in life form. The highest elevation reached by any of these woody species occurred with *Chrysothamnus viscidiflorus*, which extends to near 4000 m at the top of Barcroft Peak.

Thirteen annual species are present, making up 8% of the flora. The majority of the annual species that extend their range into the alpine zone are more typical of open habitats at lower montane or subalpine elevations. Most of the annuals are relatively uncommon.

The greatest numbers of alpine species in the White Mountain occur in habitats intermediate along a moisture gradient between wet sites with saturated soils and dry slopes (Fig. 4). Drainage courses and associated fellfield habitats with seasonal moisture availability are the typical habitat for 67 species (41% of the flora). Open slopes that become relatively dry in summer are second in significance as the characteristic habitat for 34 species (21% of the flora). Moist meadows are home to 39 species (24% of the flora), mostly graminoids. Only a small number of species typically occur on wet sites with saturated soils (11 species), aquatic habitats (1 species), or dry slopes (4 species).

Plant life forms showed mixed patterns of correlation with alpine habitats across a moisture gradient. The number of species represented in many categories, however, is too small for relevant statistical tests of association. Broad-leaved herbaceous perennials, the most common life form, have virtually the same proportional distribution among habitats as does the entire flora (Table 1). Perennial graminoids, likewise, generally match the overall pattern but with an over-representation of species in moist and wet habitats and an under-representation in drier open habitats. Among the less common life forms there is a much stronger association with specific habitats. Annual plant species are strongly associated with fellfield habitats (77% of species). Cushion plants and mats are over represented in open spaces and rocky habitats, rare in moist habitats, and absent from wet habitats. Both chamaephytes and shrubs favor open slopes and moist sites.

Separating species into categories of elevational ranges over which they occur demonstrates that 51 species (31% of the flora) are alpine specialists in the White Mountains that are largely restricted to sites above 3500 m (Fig. 5). However, a few of these alpine-restricted species in the White Mountains, as for example the aquatic *Callitriche verna* and the wet site *Juncus bryoides*, occur at lower elevations in wetter mountain ranges. Among the alpine species are seven high-elevation alpine specialists that occur only above 3960 m (Morefield et al. 1988). These species are *Erigeron vagus* (Asteraceae) *Anelsonia eurycarpa* (Brassicaceae), *Cerastium beeringianum* (Caryophyllaceae), *Polemonium chartaceum* (Polemoniaceae), and three grasses; *Elymus scribneri*, *Poa lettermanii*, and *P. suksdorfii*.

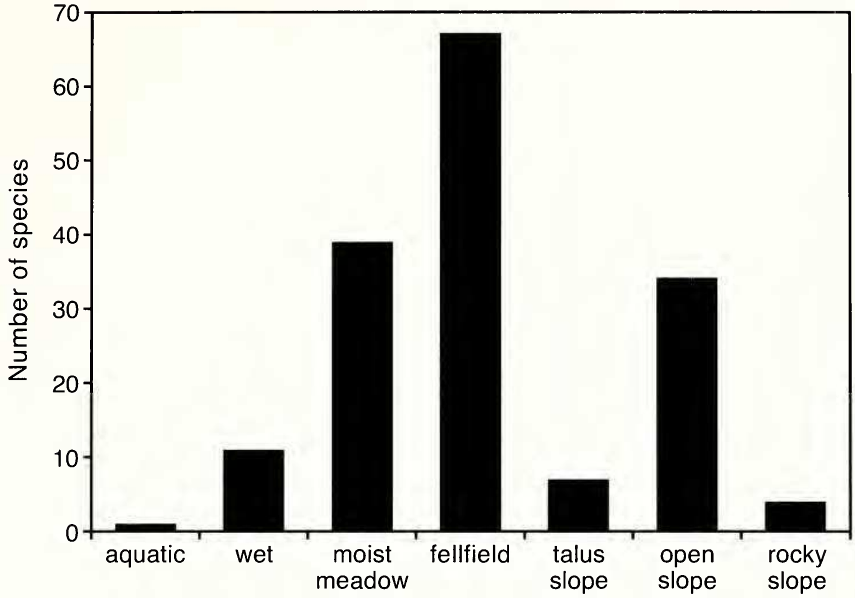

FIG. 4. Lower elevational zone of occurrence for the native vascular plant species present in the alpine zone above 3500 m in the White Mountains.

Another large group of 59 species (36% of the flora) has a range extending into the alpine zone from subalpine forests and shrublands at elevations above 2900 m. Forty-two species (26% of the flora) present in the alpine zone of the White Mountains can also be found in montane habitats as low as 1980 m. Finally, there are six species in the alpine that reach to cold desert elevations as low as 1220 m, as exemplified by *Chrysothamnus viscidiflorus* subsp. *viscidiflorus* that occurs commonly from 1550–4000 elevation.

It is instructive to combine the data on life form and elevational range of occurrence to assess if certain life forms are more likely than others to have broad elevational ranges. Among the alpine flora described here, broad-leaved herbaceous perennials, graminoids, and cushions and mats have 75%, 72% and 81%, respectively,

TABLE 1. RELATIONSHIP BETWEEN PLANT LIFE FORM AND HABITAT OF CHARACTERISTIC OCCURRENCE FOR THE ALPINE PLANT SPECIES OF THE WHITE MOUNTAINS, CALIFORNIA.

	Shrub	Chamaephyte	Cushion/ mat	Broad-leaved herbaceous perennial	Perennial graminoid	Annual	Total flora
Number of species							
Aquatic	0	0	0	0	0	1	1
Wet	0	0	0	7	4	0	11
Moist	2	2	2	20	11	2	39
Tallus slope	0	1	0	4	2	0	7
Fellfield	0	1	4	36	16	10	67
Open slope	1	3	9	18	3	0	37
Rocky site	0	0	3	1	0	0	4
Total	3	7	18	86	36	13	163
Relative values (%)							
Aquatic	—	—	—	—	—	8	0.6
Wet	—	—	—	8	11	—	7
Moist	50	29	11	23	31	15	24
Tallus slope	—	14	—	5	6	—	4
Fellfield	—	14	22	42	44	77	41
Open slope	50	43	50	21	8	—	21
Rocky site	—	—	17	1	—	—	2
Total	100	100	100	100	100	100	99.6

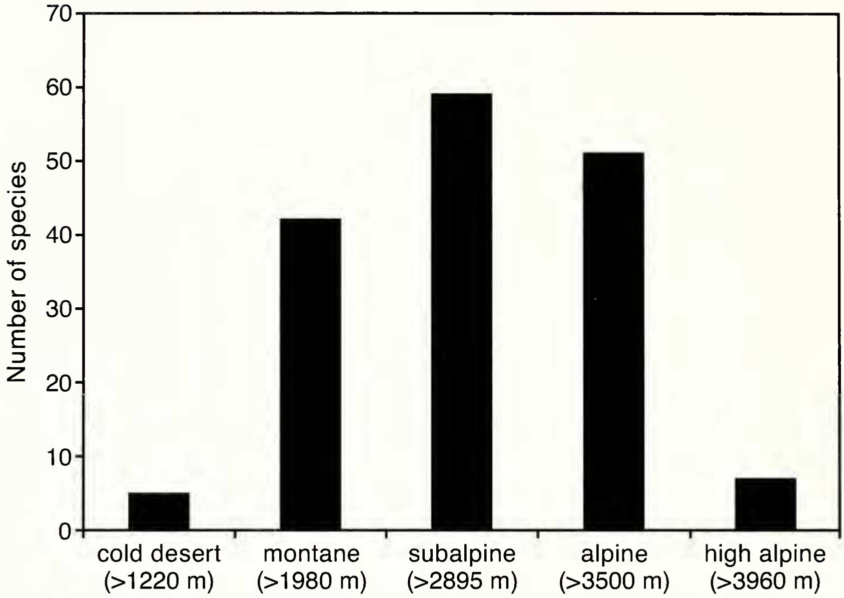

FIG. 5. Typical habitat occurrence of the native vascular plant species in the alpine zone above 3500 m in the White Mountains.

of their species restricted to subalpine and alpine habitats (i.e., elevations above 2900 m). This is a far greater proportion than that present in phanerophytes, chamaephytes and annuals where only 50%, 38%, and 54% of species respectively are limited to these higher elevations. Obligately alpine species in the White Mountains fall almost entirely into just three life forms – broad-leaved herbaceous perennials (33 species), graminoid perennials (17 species), and cushions/mats (3 species). Only one chamaephyte, *Phlox condensata*, has this elevational restriction, and it is quite mat-like in its growth habit. The two other alpine specialists are the wetland annuals *Callitriche verna* and *Juncus bryoides* that would be expected to occur at lower elevations in the White Mountains if suitable habitats were present. These data are consistent with the generalization that upright woody plants and annuals have relatively low abundance and diversity in alpine habitats.

The biogeographic affinities of the alpine flora show strong links throughout the mountains of the western United States. Only 26 species in the alpine flora are widespread or transcontinental species. The largest group, 55 species (34% of the flora), has broad linkages to western cordilleran regions including the Rocky Mountains and/or Pacific Northwest (Fig. 6). Another 36 species (22% of the flora) are linked directly to the Sierra Nevada/Cascade Ranges. Together then, more than 70% of the alpine flora of the White Mountains is shared with the Sierra Nevada. Strong biogeographic connections to the flora of the Intermountain Ranges are characteristic of 41 species (25% of the flora).

Just three species are endemic to the alpine zone of the White Mountains, while three other species come close to being endemic. The endemics are *Draba californica*, *D. monoensis*, and *Potentilla morefieldii*. The high alpine *Polemonium chartaceum* occurs principally in the White-Inyo Range with a disjunct occurrence in the Klamath Region of northern California. Recent studies have shown that these populations are morphologically distinct and deserve more careful study (Pritchett and Patterson 1998). *Draba subumbellata* and *Arabis pinzlae* reach just beyond the White Mountains into the eastern slope of the Sierra Nevada in northwestern Inyo County, and *D. sierrae* extends only slightly further into the Sierra Nevada (Price and Rollins 1988; Rollins and Price 1988; Constance-Shull and Sawyer 2000).

Introduced Flora

Alpine habitats are generally inhospitable for alien plant species, and the White Mountains are no exception. Seven species of introduced plants have been reported from the alpine zone: *Senecio vulgaris* (Asteraceae), *Capsella bursa-pastoris*, *Sisymbrium irio*, *S. orientale*, and *Descurainia sophia* (Brassicaceae), *Stellaria media* (Caryophyllaceae), and *Chenopodium rubrum* (Chenopodiaceae). The first six of these are alien to California, while the last in this list is now questionably considered to be native. All seven

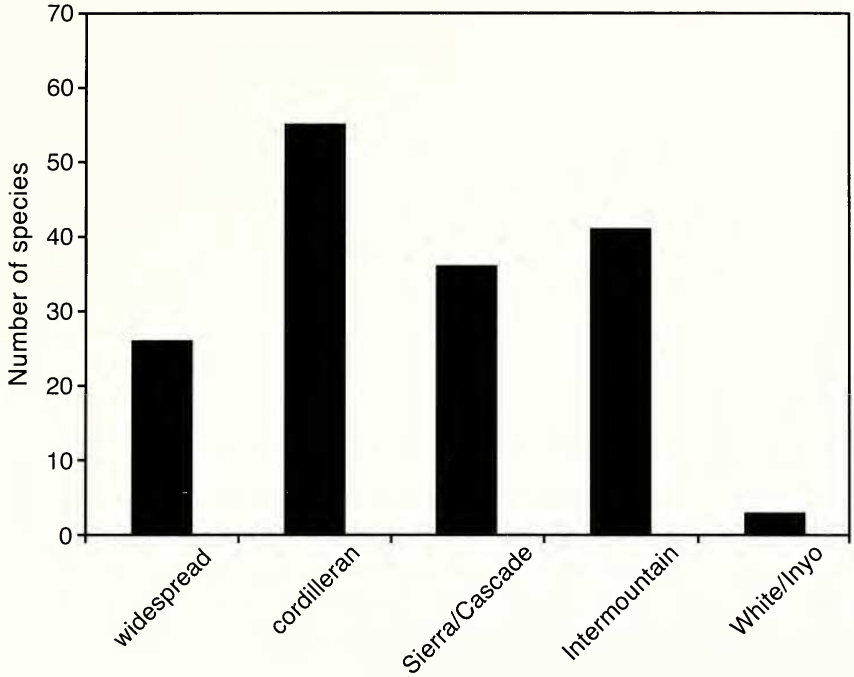

FIG. 6. Biogeographic affinities of the native vascular plant species of the alpine above 3500 m in the White Mountains.

species, however, owe their presence in the alpine zone of the White Mountains to unintentional human introduction. None of these species is well established, with only *Capsella bursa-pastoris* reported in multiple small colonies along the roadside. Six of these species are annuals attempting to survive near their upper elevational limits. The one exception is *Chenopodium rubrum*, which although an annual at lower elevations, takes on a biennial growth form in the alpine zone of the White Mountains (Spira and Wagner 1988).

DISCUSSION

Floristic Richness and Life Forms

The total flora of the White Mountains includes 988 species (Morefield 1992), and thus the alpine flora as defined here thus includes 16% of this flora.

Although conditions of the total and seasonal distribution of rains differ in alpine habitats from the Sierra Nevada eastward across the Great Basin to the Rocky Mountains, the relative dominance of a few life forms does not change dramatically across this gradient (Billings 1978, 2000). Herbaceous perennials represent the dominant life form in all of these alpine regions. This life form in alpine regions has the characteristic of maintaining large proportions of total biomass belowground where they play an important role in carbohydrate storage over the winter months (Mooney and Billings 1960; Billings 1974).

The herbaceous perennials include species with a variety of ecological forms and life history strategies of carbon allocation to belowground, aboveground vegetative, and reproductive tissues (Rundel et al. 2005). Within this broadly defined category are perennial graminoids, broad-leaved tussocks, mats and cushions, rosettes, and biennials (Raunkiaer 1934). Many of these are relatively long-lived plants surviving for decades (Billings 1974; Pollak 1991), while others are biennials living for only two years. Perennial graminoids commonly dominate plant communities of wet meadows that dry earlier than fellfield communities. In contrast, fellfield habitats exhibit a mixed dominance of mats and cushions, broad-leaved tussocks, perennial graminoids, and rosette plants (Rundel et al. 2005).

The perennial graminoids themselves include a diverse set of ecological strategies. Whereas these species comprise a large portion of the species and heavily dominate the cover of wet areas with saturated soils and moist meadows, they also include a number of more drought-adapted fellfield species as well. The fellfield grass *Muhlenbergia richardsonis*, a species with C_4 metabolism, reaches a remarkable elevation of nearly 4000 m at the summit of Mount Barcroft (Sage and Sage 2002). This is likely the highest elevation reached by any C_4 species in the United States or Canada.

Longer-lived species commonly allocate less to reproductive tissues than shorter-lived species. This can be illustrated by the alpine gentians of the White Mountains, for example, where relative allocation to reproduction in the broad-leaved tussock *Gentiana newberryi* is significantly lower than in the biennial *Gentianella tenella* and *Gentiana prostrata* (Spira and Pollak 1986). Such biennial growth forms, however, are relatively uncommon in the alpine flora White Mountains where harsh growing conditions select against plants with short life spans. Beyond these two gentians, the other six species of biennials are all members of the Brassicaceae. These are *Arabis divaricarpa*, *A. holboelii* var. *peduncuocarpa*, *A. inyoensis*, *Descurainia incana*, *Draba albertina*, and *Halimolobus virgata* (Morefield et al. 1988).

Annual plants, for the same reasons of short and severe growing conditions, are generally rare in the typical circumboreal arctic-alpine floras of the Northern Hemisphere, comprising only 1–2% of the flora (Billings 2000). Although not abundant, annuals, nevertheless, are relatively more common in the summer dry alpine of the Sierra Nevada and White Mountains where they comprise about 8% of the floras (Jackson and Bliss 1982; Jackson 1985; Spira 1987; Spira and Wagner 1988). Annual plants are largely restricted to specific habitats in the alpine zone of the White Mountains. Sandy drainage channels are the habitat for such annuals as *Cryptantha glomeriflora* (Boraginaceae), *Gayophytum racemosum* (Onagraceae), *Gymnosteris parvula* (Polemoniaceae), and *Mimulus suksdorfii* (Scrophulariaceae) (Morefield 1988; Spira 1991). Such microsites provide relatively high growing temperatures and available water early in the growing season, a time critical for annual plants to complete their life cycle.

Subshrubs and shrubs are less rich in species in the White Mountains alpine than typical circumboreal arctic-alpine floras. Their unusually low diversity in the alpine flora of the White Mountains reflects perhaps the relatively dry conditions and low nutrient availability in this area. There has been little study to date of these species in the White Mountains.

Biogeographic Patterns of Species Richness

A number of checklists of regional alpine floras exist for the western United States, and these can aid in examining patterns of biogeographic relationships. It is interesting to compare patterns of species richness among these alpine areas, although some caution is necessary because of the differing manners in how alpine zones are defined. Alpine regions of the central Rocky Mountains that extend over an extensive area of hundreds of square kilometers include 609 vascular plant species (Scott 1995). Although a specific enumeration of the alpine flora of the Sierra Nevada has not been made, it has been estimated to be about 600 species (Chabot and Billings 1972).

Alpine floras of smaller ranges across the Great Basin vary in size depending on not only the area of habitat present, but also the degree of isolation of the mountain range. In general, these small ranges with relatively low rainfall have smaller alpine floras than comparable areas of alpine habitat in either of the larger and less xeric Sierra Nevada or Rocky Mountains. Ranges lying closer to the Rocky Mountains generally show strong florisitic linkages to this range, while those lying on the western margins of the Intermountain Region have floras more strongly linked to the Sierra Nevada. Loope (1969) reported 189 alpine species from the Ruby Mountains in northeastern Nevada, with this flora showing a strong affinity to alpine floras of the Rocky Mountains. The isolated San Francisco Mountain in Arizona with only 5.2 km^2 of alpine habitat has 80 species and likewise shows strong floristic relationships to the Rocky Mountains despite its separation (Schaak 1983). In contrast, the Sweetwater Mountains lying 33 km west of the Sierra Nevada supports a flora of 173 species in 16 km^2 of alpine habitat, with 94% of this flora common to the Sierra Nevada (Bell Hunter and Johnson 1983). The small alpine zone on Mt. Grant to the north of the Sweetwater Mountains in western Nevada is just 2.6 km^2 in area supports a flora of 70 species dominated by Sierra Nevadan elements (Bell and Johnson 1980).

Comparing checklists at the species level (i.e., ignoring subspecific taxa), the alpine flora of the White Mountains exhibits a much stronger biogeographic relationship to the Sierra Nevada than to the central Rocky Mountains. Thus, 87% of the species in the alpine flora of the White Mountains are also found in the Sierra Nevada (Hickman 1993) compared with only 58% that occur in the ranges of the central Rocky Mountains (Scott 1995). These values are significantly higher for both ranges than earlier estimates made on incomplete data (Lloyd and Mitchell 1973). The alpine flora of the White Mountains, like the Sierra Nevada, lacks many of the typical circumboreal alpine species commonly present in other alpine regions of North America (Billings 2000).

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APPENDIX 1. THE NATIVE VASCULAR PLANT FLORA OF ALPINE AREAS OF THE WHITE MOUNTAINS ABOVE 3500 M ELEV. Species are listed alphabetically by family and species, with family names abbreviated by their first four letters. Species follow Hickman et al. (1993). Life forms are shrub (phanerophyte, S), chamaephyte (subshrub, CH), cushion or mat (C/M), broad-leaved herbaceous perennial (HP), perennial graminoid (G), and annual (A). Elevation zones of lowest occurrence are cold desert (CD), montane (MON), subalpine (SUBA), alpine (ALP), and high alpine (HALP). Habitat categories are aquatic (A), areas with saturated soils (W), wet meadow (M), fellfield (FF), talus slope (T), open slope (OS), and rocky slope (R). Biogeographic distribution categories are widespread (W), western cordilleran (CORD), Sierra-Cascade (S-C), intermountain (INT), and endemic (END). See text for discussion of these categories.

Species	Family	Life form	Elevation zone	Habitat	Biogeography
Pteridophyta					
Selaginella watsonii	SELG	HP	SUBA	FF	INT
Cystopteris fragilis	DRYO	HP	SUBA	FF	INT
Pellaea breweri	PTER	HP	MON	FF	INT
Angiospermae—Dicotyledonae					
Cymopterus cinerarius	APIA	HP	SUBA	OS	INT
Agoseris glauca var. *laciniata*	ASTE	HP	SUBA	FF	WIDE
Antennaria media	ASTE	C/M	ALP	M	CORD
Antennaria rosea	ASTE	HP	MON	FF	WIDE
Antennaria umbrinella	ASTE	C/M	SUBA	M	WIDE
Artemisia dracunculus	ASTE	HP	MON	FF	INT
Artemisia ludoviciana subsp. *incompta*	ASTE	HP	CD	FF	INT
Artemisia michauxiana	ASTE	HP	SUBA	M	CORD
Artemisia rothrockii	ASTE	CH	SUBA	M	S-C
Chaenactis alpigena	ASTE	HP	ALP	M	S-C
Chrysothamnus viscidiflorus subsp. *viscidiflorus*	ASTE	CH	MON	T	INT
Crepis nana	ASTE	HP	ALP	M	CORD
Ericameria discoidea	ASTE	CH	SUBA	M	INT
Ericameria suffruticosa	ASTE	CH	SUBA	FF	INT
Erigeron clokeyi	ASTE	HP	MON	OS	INT
Erigeron compositus	ASTE	C/M	MON	FF	WIDE
Erigeron pygmaeus	ASTE	C/M	ALP	FF	S-C
Erigeron vagus	ASTE	HP	HALP	FF	INT
Hulsea algida	ASTE	HP	ALP	FF	INT
Machaeranthera canescens var. *canescens*	ASTE	HP	MON	FF	CORD
Pyrrocoma apargioides	ASTE	HP	SUBA	M	S-C
Raillardella argentea	ASTE	HP	ALP	FF	S-C
Senecio integerrimus var. *major*	ASTE	HP	MON	FF	CORD
Senecio pattersonensis	ASTE	HP	ALP	FF	INT
Senecio scorzonella	ASTE	HP	SUBA	M	S-C
Senecio werneriaefolius	ASTE	HP	ALP	FF	S-C
Solidago multiradiata	ASTE	HP	SUBA	FF	CORD
Stenotus acaulis	ASTE	C/M	MON	R	INT
Townsendia condensata	ASTE	HP	ALP	OS	CORD
Townsendia leptotes	ASTE	HP	ALP	FF	CORD
Trimorpha lonchophylla	ASTE	HP	MON	M	WIDE
Cryptantha cinerea var. *abortiva*	BORA	HP	MON	OS	INT
Cryptantha glomeriflora	BORA	A	SUBA	FF	S-C
Cryptantha humilis	BORA	HP	SUBA	OS	INT
Cryptantha nubigena	BORA	HP	SUBA	FF	INT
Anelsonia eurycarpa	BRAS	HP	HALP	FF	S-C
Arabis × *divaricarpa*	BRAS	HP	ALP	OS	CORD
Arabis holboellii var. *pendulocarpa*	BRAS	HP	ALP	FF	INT
Arabis inyoensis	BRAS	HP	MON	OS	INT
Arabis lemmonii	BRAS	C/M	SUBA	OS	INT
Arabis lyalii var. *nubigena*	BRAS	HP	SUBA	OS	INT
Arabis pinzlae	BRAS	HP	ALP	FF	S-C
Arabis platysperma var. *platysperma*	BRAS	HP	SUBA	FF	S-C
Descurainia incana	BRAS	HP	MON	M	CORD
Draba albertina	BRAS	HP	SUBA	FF	CORD
Draba breweri	BRAS	HP	ALP	FF	S-C
Draba californica	BRAS	HP	ALP	M	END
Draba densifolia	BRAS	C/M	SUBA	FF	INT

Appendix 1. Continued

Species	Family	Life form	Elevation zone	Habitat	Biogeography
Draba monoensis	BRAS	HP	ALP	FF	END
Draba oligosperma var. *oligosperma*	BRAS	C/M	SUBA	OS	CORD
Draba subumbellata	BRAS	HP	ALP	T	S-C
Halimolobos virgata	BRAS	HP	SUBA	W	CORD
Lesquerella kingii subsp. *kingii*	BRAS	HP	MON	R	INT
Callitriche verna	CALL	A	ALP	A	WIDE
Arenaria kingii var. *glabrescens*	CARY	C/M	SUBA	OS	S-C
Cerastium beeringianum var. *capillare*	CARY	HP	HALP	M	WIDE
Minuartia nuttallii subsp. *gracilis*	CARY	HP	ALP	FF	CORD
Minuartia rubella	CARY	HP	ALP	FF	CORD
Minuartia stricta	CARY	HP	ALP	M	CD
Sagina saginoides	CARY	HP	MON	W	WIDE
Silene bernardina	CARY	HP	MON	OS	CORD
Silene sargentii	CARY	HP	ALP	FF	S-C
Stellaria umbellata	CARY	HP	ALP	W	WIDE
Chenopodium atrovirens	CHEN	A	CD	M	CORD
Chenopodium leptophyllum	CHEN	A	MON	FF	CORD
Monolepis nuttalliana	CHEN	A	SUBA	FF	CORD
Sedum roseum subsp. *integrifolium*	CRAS	HP	ALP	FF	WIDE
Astragalus kentrophyta var. *tegetarius*	FABA	C/M	SUBA	OS	S-C
Lupinus lepidus var. *utahensis*	FABA	HP	MON	M	CD
Oxytropis borealis var. *viscida*	FABA	HP	ALP	FF	CORD
Oxytropis parryi	FABA	C/M	SUBA	OS	INT
Trifolium andersonii var. *beatleyae*	FABA	C/M	SUBA	OS	END
Trifolium monanthum var. *monanthum*	FABA	HP	MON	M	S-C
Gentiana newberryi var. *tiogana*	GENT	HP	ALP	M	S-C
Gentiana prostrata	GENT	HP	SUBA	M	WIDE
Gentianella tenella subsp. *tenella*	GENT	HP	MON	W	WIDE
Ribes cereum	GROS	P	MON	OS	INT
Nama densum	HYDR	A	MON	FF	INT
Phacelia hastata subsp. *compacta*	HYDR	HP	MON	OS	S-C
Linum lewisii var. *alpicola*	LINA	HP	ALP	OS	INT
Gayophytum racemosum	ONAG	A	SUBA	FF	CORD
Gymnosteris parvula	POLE	A	SUBA	FF	CORD
Ipomopsis congesta subsp. *montana*	POLE	HP	MON	FF	S-C
Leptodactylon pungens	POLE	CH	SUBA	OS	CORD
Linanthus nuttallii subsp. *pubescens*	POLE	CH	MON	OS	CORD
Phlox condensata	POLE	C/M	MON	OS	CORD
Phlox pulvinata	POLE	CH	ALP	OS	CORD
Polemonium chartaceum	POLE	HP	HALP	OS	END
Eriogonum gracilipes	POLY	C/M	SUBA	R	INT
Eriogonum lobbii var. *lobbii*	POLY	HP	ALP	FF	S-C
Eriogonum ovalifolium var. *nivale*	POLY	C/M	SUBA	OS	INT
Eriogonum rosense	POLY	C/M	MON	R	INT
Eriogonum spergulinum var. *reddingianum*	POLY	A	MON	FF	INT
Oxyria digyna	POLY	HP	ALP	M	WIDE
Rumex paucifolius	POLY	HP	SUBA	OS	S-C
Calyptridium roseum	PORT	A	MON	FF	INT
Calyptridium umbellatum	PORT	HP	SUBA	FF	CORD
Lewisia pygmaea	PORT	HP	ALP	FF	CORD
Montia chamissoi	PORT	HP	MON	W	S-C
Androsace septentrionalis subsp. *subumbellata*	PRIM	HP	ALP	OS	CORD
Dodecatheon redolens	PRIM	HP	MON	W	INT
Ranunculus alismifolius var. *alismellus*	RANU	HP	SUBA	W	S-C
Ranunculus eschscholtzii var. *oxynotus*	RANU	HP	ALP	T	S-C
Ranunculus glaberrimus var. *ellipticus*	RANU	HP	SUBA	M	CORD
Thalictrum alpinum	RANU	HP	MON	M	WIDE
Ivesia gordonii	ROSA	HP	ALP	OS	INT
Ivesia lycopodioides subsp. *scandularis*	ROSA	HP	ALP	M	INT
Ivesia shockleyi var. *shockleyi*	ROSA	C/M	ALP	OS	S-C
Potentilla fruticosa	ROSA	P	MON	M	WIDE

Appendix 1. Continued

Species	Family	Life form	Elevation zone	Habitat	Biogeography
Potentilla glandulosa subsp. *pseudorupestris*	ROSA	HP	ALP	OS	CORD
Potentilla morefieldii	ROSA	HP	SUBA	OS	END
Potentilla pensylvanica	ROSA	HP	SUBA	FF	WIDE
Potentilla pseudosericea	ROSA	HP	ALP	FF	CORD
Sibbaldia procumbens	ROSA	HP	ALP	FF	WIDE
Galium multiflorum	RUBI	HP	SUBA	T	INT
Salix orestera	SALI	P	SUBA	M	S-C
Heuchera duranii	SAXI	HP	SUBA	T	CORD
Castilleja nana	SCRO	HP	SUBA	OS	INT
Mimulus mephiticus	SCRO	A	SUBA	T	S-C
Mimulus primuloides subsp. *primuloides*	SCRO	HP	MON	M	S-C
Mimulus suksdorfii	SCRO	A	SUBA	FF	INT
Pedicularis attollens	SCRO	HP	SUBA	M	S-C
Penstemon heterodoxus var. heterodoxus	SCRO	C/M	SUBA	FF	S-C
Angiospermae—Monocotyledonae					
Carex albonigra	CYPE	G	ALP	M	CORD
Carex breweri var. *breweri*	CYPE	G	ALP	W	S-C
Carex capitata	CYPE	G	ALP	W	WIDE
Carex douglasii	CYPE	G	CD	M	CORD
Carex eleocharis	CYPE	G	SUBA	FF	CORD
Carex filifolia var. *erostrata*	CYPE	G	SUBA	M	CORD
Carex haydeniana	CYPE	G	SUBA	M	CORD
Carex helleri	CYPE	G	ALP	FF	S-C
Carex heteroneura var. *heteroneura*	CYPE	G	SUBA	W	INT
Carex microptera	CYPE	G	MON	M	CORD
Carex phaeocephala	CYPE	G	SUBA	FF	CORD
Carex straminiformis	CYPE	G	SUBA	M	S-C
Carex subnigricans	CYPE	G	ALP	M	INT
Carex vernacula	CYPE	G	ALP	M	CORD
Eleocharis pauciflora	CYPE	G	MON	W	WIDE
Juncus balticus	JUNC	G	SUBA	M	CORD
Juncus bryoides	JUNC	G-A	ALP	FF	CORD
Juncus nevadensis	JUNC	G	MON	M	CORD
Juncus parryi	JUNC	G	ALP	FF	CORD
Luzula spicata	JUNC	G	ALP	FF	WIDE
Achnatherum pinetorum	POAC	G	MON	OS	INT
Calamagrostis purpurascens	POAC	G	MON	FF	WIDE
Deschampsia cespitosa subsp. *cespitosa*	POAC	G	ALP	M	WIDE
Elymus elymoides	POAC	G	MON	OS	CORD
Elymus scribneri	POAC	G	HALP	T	CORD
Elymus trachycaulus subsp. *subsecundus*	POAC	G	MON	FF	WIDE
Festuca brachyphylla subsp. *breviculmis*	POAC	G	SUBA	FF	WIDE
Festuca minutiflora	POAC	G	SUBA	FF	CORD
Koeleria macrantha	POAC	G	SUBA	OS	WIDE
Muhlenbergia richardsonis	POAC	G	MON	FF	CORD
Poa abbreviata subsp. *pattersonii* and subsp. *marshii*	POAC	G	HALP	FF	CORD
Poa cusickii subsp. *epilis*	POAC	G	SUBA	FF	CORD
Poa glauca subsp. *rupicola*	POAC	G	ALP	FF	CORD
Poa keckii	POAC	G	ALP	T	S-C
Poa lettermanii	POAC	G	HALP	FF	CORD
Poa secunda subsp. *secunda*	POAC	G	CD	FF	CORD
Trisetum spicatum	POAC	G	SUBA	FF	WIDE